Evaluation of irrigation water quality under newly weathered soil in hot and semi-humid region of central India

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Abstract

Throughout the pre-monsoon, monsoon, and post-monsoon seasons, the participants in this research took water samples that were later examined for a variety of physiochemical characteristics. Irrigation water quality metrics such as SAR, RSC, Na%, KR, MHR, PS, PI, and RSBC were used in conjunction with the calculation of IWQI in order to conduct an evaluation of the appropriateness of the irrigation water. The major dominated anions in the study area were found HCO_3^- > SO_4^{2-} > Cl^- during all the season, while cation was fluctuated from Na^+ > Mg^{2+} > Ca^{2+} > K^+ at pre-monsoon season and Na^+ > Ca^{2+} > Mg^{2+} > K^+ at both monsoon and post-monsoon season. Ca (Mg)- HCO_3^-, Na- $HCO_3^-$and mixed type water was found in the study area which was originated from the silicate weathering and evaporate dissolution. Some samples were reported with high KR, MHR, Na%, RSC, PS and RSBC which exceeding limit and unsuitable for irrigation use. Out of the total collected water samples 32%, 64%, 8%, 44%, 12%in pre-monsoon and 24%, 60%, 8% 16%, 12% in post-monsoon period were not suitable for irrigation purpose with having high KR, MHR, Na%, RSC and PS, respectively. While, 8% (KR), 52% (MHR), 12%(RSC) and 8% (PS) was also unsuitable for irrigation purpose during monsoon period. However, the IWQI of the study area was noted 48% water sample having above the limit > 100 which was unsuitable for irrigation water.

1. Introduction

Water is an essential for all living things which requires for the metabolic activities (Kumbhar et al., 2014). Today water scarcity is a major problem both in terms of quality and quantity and it continuously rises due to huge pressure of urbanization, industrialization and deforestation which ultimately deteriorate surface and groundwater quality. Good water quality is also play role for the socio-economic development of the society (Avtar et al., 2013). Irrigated agriculture having major attention since green revaluation era with doubling agriculture production as compared rainfed agriculture. Continuous application of bad quality of irrigation may increase the negative impact on soil quality in term of heavily accumulation of undesirable salt and degrade the physico-chemical properties of soil which ultimately effects on plant growth. Elevated salt content in irrigation water may also involving for clogging of irrigation delivery systems specially in the drip system and increasing maintenance cost (Bornare et al., 2018). The quality of water depends on both the natural and anthropogenic process and its determination is an important tool for the sustainable agriculture development (Yildiz and Karakus, 2019). The quality of irrigation water governs the presence of different ions like pH, EC, cations and anions (Karakus and Yildiz, 2019, Singh et al., 2015; Abdessamed et al., 2021). The study area covers in the Bundelkhand region of central India which comprises seven districts from Uttar Pradesh (Jhansi, Chitrakoot, Mahoba, Banda, Hamirpur, Jalaun and Lalitpur) and seven district from Madhya Pradesh (Datia, Damoh, Panna, Tikamgarh, Niwari, Chhatarpur and Sagar). Bundelkhand region suffering water scarcity from long time for agricultural and other use. The study area covering three major types of rocks namely Bundelkhand complex, Bijawar group and Vindhayan super group. Whereas, Bundelkhand granite complex were dominating in this area, which contains 28–44% plagioclase, 19–39% quartz, 19–27% feldspar as albite and orthoclase, 3–8% Hornblende 1–3% biotite, and other minerals were found small quantity in study area (Ray et al., 2016). Surface and groundwater were shrinking in this region due to having low rainfall which is not sufficient to replenish the amount of utilized water from groundwater sources. Researchers from a variety of fields have utilised a number of different parameters in order to assess the quality of irrigation water. Some of these parameters include the sodium adsorption ratio (SAR), the Kelly ratio (KR), the potential salinity (PS), the magnesium hazard ratio (MHR), the sodium percentage (Na%), the residual sodium carbonate (RSC), the residual sodium bicarbonate (RSBC), and the permeability index (PI) (Mufeed et al., 2021; Dash and Kalamdhad, 2021;Ustaoglu et al., 2021;Elsayed et al., 2020). In addition, the FAO standard value is compared to a single numeric value known as the irrigation water quality index (IWQI), which is used for determining the quality of irrigation water (Abbasnia et al., 2018;Ghazaryan et al., 2020).

This study helps to determine and identify the dominant cation and anion in the irrigation water with their hydro-geochemistry which responsible for the degradation of irrigation water quality and it also give a basic idea about best management options. In this study various physico-chemical properties pH, EC, TH, Cl^-, SO_4^{2-}, CO_3^{2-}, HCO_3^- Ca^{2+}, Mg^{2+}, Na^+ and K^+ were analysed in different dry and wet season. Well established method of SAR, RSC, KR, PS, MHR, PI, Na%, RSBC, IWQI, USSL and Wilcox plot were used for the evaluation of irrigation water suitability. Piper trilinear and Gibbs plot were used to understand the hydro-geochemistry of sampled water and their relations. For the better understanding of seasonal variation of water quality spatio-temporal map has been prepared.

2. Materials And Methods

2.1 Study area

The area is situated under the climatic condition of hot and semi-humid region of central India where, average annual rainfall is 850 mm. The climate was hot and dry during summer and cold in winter. However, most of the rainfall about 90% fall between June to September month. Red and black soil was found in this area which further categorized red soil is Rakar and Parwa and Black soil under Mar and Kabar. The Bundelkhand granite gneissic complex geology was observed in the area (Prasad, 2008). Sub-surface water and canal water are the main source of irrigation for the crop production where only 41% area was irrigated land in which 54% irrigated from groundwater and remains from canal and pond water.

2.2 Sampling and analysis

During the pre-monsoon, monsoon, and post-monsoon periods, a total of 75 water samples were collected using a Global Positioning System (GPS) in a plastic bottle with a capacity of 500 ml from various surface and groundwater sources. Twenty-five samples were collected during each season, as shown in Fig. 1. Various hydrochemical parameters, such as pH, electrical conductivity (EC), chloride (Cl^-), sulphate ($SO4^{2-}$), carbonate (^{CO32}-), bicarbonate (HCO^{3-}), total hardness (TH) as $CaCO_3$, calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), and potassium (K^+), were evaluated using samples of water. The APHA standards and procedures for analysis of various types of water and wastewater were used to conduct analyses on all of the parameters found in the water samples (APHA, 1999). With the assistance of ArcGIS-10.4, the IDW interpolation approach was used for the purpose of determining the geographical distribution of water quality.

< Insert Fig. 1

Different sampling location of water in the study area. >

2.3 Irrigation water quality

Several different calculative parameters, such as sodium percentage (Wilcox 1955), permeability index (Doneen 1962), residual sodium bicarbonate (Eaton 1950), potential salinity (Doneen 1964), Kelly ratio (Kelly 1963), magnesium hazard ratio (Raghunath 1987), sodium adsorption ratio (Richards 1954), and residual sodium carbonate (Eaton 1950), were used to evaluate the quality of irrigation water and determine its suitability for use. They are determined by making use of the following formulae, and all of the values that are calculated are represented in meq/l units.

$$SAR = \frac{Na^{+}}{\sqrt{Ca^{2+} + Mg^{2+}/2}}$$

$$Na\,(\%) = \frac{Na^{+}}{(Ca^{2+} + Mg^{2+} + Na^{+})} \times 100$$

$$RSC = \left(HCO_3^{-} + CO_3^{2-}\right) - (Ca^{2+} + Mg^{2+})$$

$$MHR = \frac{Mg^{2+}}{(Ca^{2+} + Mg^{2+})} \times 100$$

$$KR = \frac{Na^{+}}{(Ca^{2+} + Mg^{2+})}$$

$$PI\,(\%) = \frac{(Na^{+} + \sqrt{HCO_3^{-}}}{(Ca^{2+} + Mg^{2+} + Na^{+})} \times 100$$

$$PS = Cl^{-} + \left(\frac{SO_4^{2-}}{2}\right)$$

$$RSBC = HCO_3^{-} - Ca^{2+}$$

2.4 Irrigation water quality index (IWQI)

It is possible to assess it by contrasting the measured value of water quality indicators with the standard value specified by the Food and Agriculture Organization of the United Nations (FAO) (Ayers and Westcot 1994). The parameters and their relative weight were used for IWQI calculation are indicated in supplementary table 1 and it evaluated by using following equations.

$$IWQI = \Sigma_{i=1}^{n} Si \times RWi$$

$RWi = \frac{Wi}{\Sigma_{i=1}^{n} Wi}$ and

$$Wi = \frac{1}{V_{Standard}}$$

Where, Wi is the unit weight of ith factor, Si is permissible limit of nth factor and $V_{Standard}$is the standard value of FAO.

Si is the quality rating scale of the ithparameters for all n water quality parameters. It was computed as follows;

$$Si = \left[\frac{Va - Vi}{V_{std} - Vi}\right] X100$$

Where, $Va$is a actual detected value of the parameters

Vi is a Ideal value of the parameters in pure water

V_{std} is standard value of the parameters

The ideal value for pH = 7 and zero for the other parameters were used (Salam and Salwan, 2017).

< Insert Supplementary Table 1

Water quality standards used for irrigation water quality index.>

3. Results And Discussions

3.1 Physico-chemical properties of water

The water quality has been assessed based on tested various physico-chemical properties during three seasons as indicated in Table 1. During pre-monsoon season pH was observed under neutral to alkaline in nature which was ranged from 6.9to 8.1 (average 7.7). EC and TDS of the sampled water were 218.70 μS/cm – 832.70 μS/cm (mean 528.18 μS/cm) and 146.53 mg/l – 557.91 mg/l (mean 353.88 mg/l), respectively. Hardness of water ranged from 50 – 470 mg/l (mean 247mg/l). The HCO_3^-, SO_4^{2-}, Cl^- and CO_3^{2-} was tested but the carbonate content was not found and the following sequence of anionic concentration was observed HCO_3^-> SO_4^{2-}> Cl^-in the study area.The maximum (774.4mg/l) HCO_3^- content was reported in groundwater sample and minimum was (256.27 mg/l) in pond water with having mean value of 412.47 mg/l. Whereas, SO_4^{2-} concentration in collected water was varied from 27.52 – 479.20 mg/l with 123.54 mg /l mean value. While chlorine ion was ranged from 19.45 mg/l to 85.95 mg/l with an average value of 49.30 mg/l. The cation order Na^+> Mg^{2+}> Ca^{2+}> K^+ was dominated in sampled water during pre-monsoon season whereas, calcium ions varied between 4 mg/l to 104.20 mg/l (mean 37.15 mg/l) and Mg^{2+} was 3.05 mg/l – 65.54 mg/l (average 37.57 mg/l). However, Na^+ and K^+ was ranged from 33.40 mg/l – 178.0 mg/l (mean 85.89 mg/l) and 0.30 mg/l – 11.10 mg/l (average 3.30 mg/l), respectively.

< Insert Table 1: Descriptive statistics of collected water samples during all the season.>

In monsoon season pH and EC was ranged from 6.7 to 7.7 with a mean value of 7.7 and 200 μS/cm to 1020 μS/cm (mean 507.22 μS/cm). TDS of collected water was noted 134.0 mg/l to 683.40 mg/l (average 339.83 mg/l) and TH was 48.0 mg/l – 640.0 mg/l with an average value of 357.68 mg/l. The decreasing order of cation and anions was Na^{+}> Ca^{2+}> Mg^{2+}> K^{+} and HCO_3^{-}> SO_4^{2-}> Cl^{-}reported. The Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} were ranged from 15.45 mg/l – 154.30 (mean 70.71 mg/l), 1.27 mg/l –123.83 mg/l (mean 43.98 mg/l), 25.76 mg/l – 163.0 mg/l (average 77.10 mg/l) and 0.20 – 12.0 mg/l (average 3.41 mg/l), respectively. Whereas HCO_3^{-} was 237.96 mg/l – 707.79 mg/l (mean 421.74 mg/l), SO_4^{2-} was much fluctuated from 18.0 mg/l to 459.20 mg/l (105.03 mg/l) and Cl^{-} was 12.0 mg/l to 130.96 mg/l (mean 44.26 mg/l).

During post monsoon season pH was observed 6.7 – 7.9 (mean 7.3) and EC was ranged from 215.40μS/cm – 866.70 μS/cm (mean 508.18 μS/cm). Whereas, TDS in sampled water was 144.32 mg/l – 580.69 mg/l (average 340.44 mg/l) and TH of collected water varied from 40.0 mg/l – 630.0 mg/l (mean 345.44 mg/l). However, Cl^{-} and HCO_3^{-} was found between 12.0 mg/l – 127.96 mg/l (mean 47.26 mg/l) and 134.23 mg/l - 610.16 mg/l (mean 350.96 mg/l), respectively.While, the sulfate ion in water sample was found between 20.0 mg/l – 466.0 mg/l (mean 110.78 mg/l). The cation was mainly Ca^{2+}detected from 8.0 mg/l – 137.87 mg/l (mean 58.81 mg/l), Mg^{2+} was 1.66 mg/l – 134.52 mg/l (average 48.22 mg/l), Na^{+} was 27.30 mg/l – 158.40 mg/l (mean 77.10 mg/l) and K^{+} was found 0.10 mg/l – 11.80 mg/l (mean 3.20 mg/l). Meanwhile the ionic sequence was observed Na^{+}> Ca^{2+}> Mg^{2+}> K^{+} and HCO_3^{-}> SO_4^{2-}> Cl^{-}in sampled water sample (Maleki and Jari, 2021; Qureshi et al., 2021).

3.2 Irrigation water suitability

Irrigation is an important input for the agriculture system and its quality affect the quality production of crops and soil health. Irrigation water suitability explained here based on the tested parameters indicated in Table 3with spatio-temporal distribution of irrigation water quality aresuggested in Fig. 4.

3.2.1 Sodium Adsorption Ratio (SAR)

High SAR water reduce the crop yield due to accumulation of Na ion in plant body which interacted with the photosynthetic activity and ultimately leaves fall (Bortolini et al., 2018;Abdessamed et al., 2021;Sara et al., 2019) and permeability of soil affected consequently weak internal drainage. The SAR ranges during pre-monsoon was 1.57 – 4.90 (mean 2.47), monsoon 0.91 – 3.64 (mean 1.91) and post-monsoon was 0.99 – 3.94 (mean 2.0) are indicated in Table 3. All the sampled water having < 10 SAR value which was excellent for the irrigation purpose.

< Insert Table 2: Classification of irrigation water quality based on EC value during pre, post and monsoon season. >

As Fig 2 suggested SAR vs EC as US salinity laboratory (USSL) diagram has been categorized four groups of sodium hazard level (S1, S2, S3, S4) and salinity hazard (C1,C2,C3, C4). Whereas, all water samples were fall under the S1C2 and S1C3 classes during all the season.

< Insert Fig 2: USSL diagram of the irrigation water suitability. >

3.2.2 Sodium percent (Na %)

Elevated Na content in the soil affect the aggregation properties of soil and act as a dispersing agent which destroys the soil aggregates.When Na^+ combine with Cl^-may accelerate the formation of saline soil and reduce the infiltration rate. However, the Na% was varied between 27.68- 61.28 %, 17.05-56.57 % and 17.84- 61.95 % at pre-monsoon, monsoon and post-monsoon period, respectively. Table 4 classified the Na% as excellent, good, permissible, doubtful and unsuitable category. Whereas, only 8 % sampled water fall under doubtful category as Wilcox and Eaton classifications at pre- and post-monsoon season which may be problematic in future. As Fig 3 suggested most of the water belongs under excellent to good and good to permissible class except only one sample in permissible to doubtful class during pre-monsoon period.

< InsertFig 3: Wilcox diagram of irrigation water suitability.>

3.2.3 Residual sodium carbonate (RSC)

The bicarbonate of Ca and Mg transformed to insoluble carbonate and it precipitated in irrigation pipe and clog the emitters.

$Ca(HCO_3)_2 \rightarrow Dry \rightarrow CaCO_3 + CO_2 + H_2O \uparrow$

High bicarbonate content in irrigation water directly damages on leaf, fruits and in soil SAR and pH was enhanced (Radingoana et al., 2020). The RSC was obtained from -3.0 to 9.0 meq/l in pre-monsoon, -7.19 to 8.0 meq/l in monsoon and -7.29 to 6.8 meq/l in post monsoon. Table 4 and Fig 4 indicated almost 44 % water sample having high RSC value (> 2.25 meq/l) during pre-monsoon season and unsuitable for irrigation due to heavy loading of HCO_3^- content. Most of the collected water having good RSC at monsoon and post-monsoon periods which is good for irrigation but only 12 % and 16 % water was unsuitable for irrigation water at monsoon and post-monsoon season, respectively. Negative value of RSC represents Na^+ was dominated and Ca^{2+} and Mg^{2+} precipitated as CO_2, whereas the positive value denotes high HCO_3^- content as reacted with Ca and Mg and form bicarbonate of Ca and Mg.

< Insert Table 3: Statistical summary of the calculated different irrigation water quality during pre,during and post -monsoon season of the study area.>

3.2.4 Magnesium hazard ratio (MHR)

The value of MHR > 50 is harmful for soil and unsuitable as irrigation waterwhich ranges from 16.55-96.0 (mean= 62), 2.55 – 83.59 (mean = 43.26) and 3.42 – 88.90 (mean = 48.66) at pre, monsoon and post-monsoon season, respectively. Table 4 indicated most of the sampled water 64 % in pre-monsoon, 52 % in monsoon and 60% in post-monsoon season were unsuitable for irrigation because it exceeds the limit (> 50) and remaining water can be used safely for irrigation.

3.2.5 Kelly ratio (KR)

High KR value obtained due to heavily cation exchange anddominated with Na^+. KR in pre-monsoon was 0.38 –1.55, monsoon 0.19 – 1.26 and in post monsoon 0.21 – 1.52. Table 4 represents most of the sampled water were suitable for irrigation at 68 % in pre-monsoon, 92% in monsoon and 76 % in post-monsoon periods, while the 32 %, 8 % and 24 % collected water sample were unsuitable as irrigation water due to having > 1 KR value in pre, during and post-monsoon season, respectively.

< Insert Table 6: Irrigation water quality parameters and their percent contribution in the study area.>

3.2.6 Permeability index (PI)

The permeability index of irrigation water was observed 47.03 – 152.20 % at pre-monsoon, 34.45 -154.72 % at monsoon and 34.94 – 160.40 % at post-monsoon period. All the collected water sample was suitable for irrigation use which is fall under the excellent and good water quality with respect to the permeability index (Table 4).

3.2.7 Potential salinity (PS)

The PS ranged between 1.04 – 6.87 meq/l (mean = 2.68 meq/l), 0.78- 6.25 meq/l (mean = 2.34 meq/l) and 0.76- 6.96 meq/l (mean = 2.49 meq/l) at pre, during and post monsoon season in the study area. Table 4 indicated that potential salinity categorized in three classes i.e. suitable (<3), good to injurious (3-5) and injurious to unsatisfactory (>5). Whereas, most of the collected water was 72 % at pre-monsoon, 68 % at monsoon and 64 % in post monsoon season were suitable for irrigation and 16 %, 24 %, 24 % fall under good to injurious water while, only 12 % , 8% , 12% irrigation water was not suitable as an irrigation water with respective season.

3.2.8 Total hardness (TH as $CaCO_3$)

Total hardness as $CaCO_3$ was varied 50 – 470 mg/l (average = 247.60 mg/l) at pre-monsoon, 48 - 640 mg/l (average = 357.68 mg/l) at monsoon and 40 – 630 mg/l (average = 345.44 mg/l) at post-monsoon season. As table 4 suggested that most of the sampled water was hard and very hard nature except few samples, whereas 72%, 40%, 44% water sample was hard water and 20%, 56% and 48 % water sample were considered as very hard water during pre-monsoon, monsoon and post- monsoon season, respectively.

3.2.9 Residual sodium bicarbonate (RSBC)

The RSBC of the sampled water was 0.9 – 10.70 meq/l during pre-monsoon, -2.10 to 8.30 meq/l during monsoon season and -1.88 to 7.20 meq/l observed during post-monsoon season. Most of the collected water was fall under the safe and marginal classes except only 4% water was found unsatisfactory for irrigation water during pre-monsoon season (Table 4).

< Insert Fig 4: Spatio-temporal distribution of irrigation water quality in the study area.>

3.3 Irrigation water quality index (IWQI)

Irrigation water quality index representing a single value for the irrigation quality with consideration of certain standards (Singh et al., 2018;Sutradhar and Mondal, 2021). The index value exceeding > 100 it may be harmful for the continuous use of irrigation water. Almost half 48 % of the sampled water was unsuitable for irrigation in all the season due to having >100 IWQI as calculated based on the FAO standards (Table5).

However, 20% water sample as reported very poor class and 16 % water as poor water, while the 8 % sampled water fall under each excellent and good condition during pre-monsoon season. During monsoon season it fall under excellent (12%), good (24%) and poor (16%) water quality index. Whereas, good (36%), excellent (12%) and poor (4%) irrigation water quality index was reported during post-monsoon season. The spatio-temporal distribution of IWQI is depicted in Fig 5.

< **Insert Table 5**: Classification of irrigation water quality index for irrigation suitability of study area. >

< **Insert Fig.5:** Spatial and temporal distribution of IWQI in the study area.>

3.4 Hydro-geochemistry of water

The ionic concentrations of cation and anion were plotted in the Piper trilinear diagram (Piper1953) as suggested in Fig 6, to known dominancy of ionic concentration in sampled water. The cations are clustered within the plot area was covered mostly about 56 % of no dominant type, 40 % Na^+ + K^+ and only 4 % Mg^{2+} type in pre-monsoon season. However, most of the collected water having 60% no dominant type, 20% Na^++K^+, 12% Mg^{2+} and 8% Ca^{2+}during monsoon season and 44 % were no dominant type 28 % Na^+ +K^+, 24% Mg^{2+}, 4 % Ca^{2+} in post-monsoon season.While, the anions concentration was aggravated within the HCO_3^-90%, 90% and 80%, no-dominant type 10%, 5% and 10% and SO_4^{2-} - 0%, 5% and 5 -10%, respectively during pre-monsoon, monsoon and post-monsoon period. The study area was mainly dominated with Ca (Mg)- HCO_3^-, Na-$HCO_3^-$and mixed type water. Ca (Mg)-HCO_3^- type water was originated in the study area where source of calcium and magnesium from the weathering of different minerals which are present in soil system. The Ca-Mg-HCO_3^- type water originated by rock water interaction with dissolution the silicate minerals of plagioclase, feldspars and ferromagnesium mineral with presence of CO_2(Singh et al., 2013). Whereas the Fig 6bsuggested that most of the surface water sources like pond water having high content of Na^+ and $K^+$and HCO_3^- as compared to the other sources. The source of Ca^{2+}, Mg^{2+} and $Na^+$was from the dominated minerals such as amphiboles, pyroxenes, biotite, anorthite and orthoclase .High concentration of K^+ in some water samples was hydrolysis of K-bearing minerals and accumulated in surface water bodies (Singh et al., 2008).

< **Insert Fig 6:** Piper trilinear diagram of sampled water in the study area **a**) season wise and **b**) source wise.**>**

< **Insert Fig 7:**Gibbs plot of the different collected water samples from the study area.>

The plot between the Ca2+/Na+ vs Mg2+/Na+ and Ca2+/Na+ vs HCO3-/ Na+ (Gaillardet et al., 1999) was used to evaluate the solute contribution in various water sample either by weathering or dissolution of the silicate, carbonate, and evaporite. This was done by Gaillardet et al., 1999. As shown in Figure 8, the majority of the data from the various water samples fell into the silicate weathering site, while only a small number of samples fell into the evaporite dissolution site. This indicates that the various ions found in the collected water samples originated from the weathering of the silicate clay minerals that are present in the soil.

< **Insert Fig 8:** Plot between the Ca^{2+}/Na^+ vs Mg^{2+}/Na^+ and Ca^{2+}/Na^+ vs HCO_3^-/ Na^+ in the study area.>

The hydro-geochemistry of the water was suggesting weathering of silicate bearing minerals such as feldspars, mica, plagioclase, amphiboles and pyroxenes a composition of Bundelkhand granite present in the study are the source of different cation and anion in water sample. Possible chemical reactions for the Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} and HCO_3^{-} content in the study area (Mirza et al., 2017) are:

$2NaAlSi_3O_8 + 9H_2O + 2H_2CO_3 \rightarrow Al_2Si_2O_5(OH)_4 + 2Na + 2HCO_3 + 4H_4SiO_4$

(Albite)

$CaAl_2Si_2O_8 + 2CO_2 + 3H_2O \rightarrow Al_2Si_2O_5(OH)_4 + Ca + 2HCO_3$

(Anorthite)

$2KMg_3AlSi_3O_{10}(OH)_2 + 14\ CO_2 + 15\ H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 2K + 6Mg + 14\ HCO_3 +$

(Biotite) $4H_4SiO_4$

$CaMgFeAl_2Si_3O_{12} + 6CO_2 + 5H_2O \rightarrow Al_2Si_2O_5(OH)_4 + Ca + Mg + Fe + 6HCO_3 + SiO_2$

(Augite)

Bicarbonate was also derived from the sub-soil zone where elevated CO_2 present due to decomposition of organic matter and root respiration meanwhile, these $CO_2$was further interacted with water molecules and formed bicarbonate content.

$CO_2 + H_2O \rightarrow H_2CO_3$

$H_2CO_3 \rightarrow H^{+} + HCO_3^{-}$

Conclusions

Water is a prime natural resource and important input for the agricultural production system. In the study area different water samples were collected from the various sources and irrigation water quality has been evaluated. A total 75 water samples collected in pre- monsoon, during-monsoon and post-monsoon season (25 samples from each season) and various physico-chemical parameters were namely pH, EC,TH as $CaCO_3$,Ca^{2+},Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, CO_3^{2-} and HCO_3^{-}analyzed which was used for the evaluating irrigation water quality i.e. SAR, Na%, RSC, MHR, KR, PI%, PS and RSBC, however the IWQI was also calculated in sampled water comparing with the FAO standards. The anions were mainly dominated with $HCO_3^{-}> SO_4^{2-}> Cl^{-}$ in all the season but cation was dominated with having $Na^{+}> Mg^{2+}> Ca^{2+}> K^{+}$at pre-monsoon period and $Na^{+}> Ca^{2+}> Mg^{2+}> K^{+}$ at monsoon and post-monsoon period. Piper trilinear diagram explains that sampled water was dominated with Ca (Mg)- HCO_3^{-}, Na-$HCO_3^{-}$and mixed type water which was originated from the weathering of different minerals and evaporite dissolution present in soil system. Whereas, the PCA was also used to separate the dominated ions contribution in the study area. The KR, MHR, %Na, RSC, PS and RSBC were observed unsuitable for irrigation purpose in few samples or it may be harmful for soil and crops when it applied for longer periods in this region. US salinity laboratory (USSL) and Wilcox diagram was used for the classification of irrigation water, which explains the low sodium water with having excellent, good and doubtful level of salinity in the study area. Most of the collected water samples was unsuitable for irrigation having >100 IWQI as calculated based on the FAO standards. This study helps to understand the hydrochemistry of water and their suitability for irrigation purpose particularly in newly weathered soil condition of hot and semi-humid area.

Declarations

Ethics approval

Not applicable

Consent to participate

Verbal consent was obtained from respondents to participate before interaction

Consent to Publish

All authors consent to the publication of the manuscript

Author Contributions: Conceptualization, Pavan Kumar and Bharat Lal; methodology, Bharat Lal and Abhishek Kumar; software, Pavan Kumar and Bharat Lal; validation, Y Singh and SK Chaturvedi; formal analysis, Susheel Kumar Singh; investigation, Pavan Kumar and Bharat Lal; writing—original draft preparation, Bharat Lal; writing—review and editing, Pavan Kumar; supervision, Y Singh ans SK Chaturvedi. All authors have read and agreed to the published version of the manuscript.

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Tables

Table 1: Descriptive statistics of collected water samples during all the season.

Parameters	Pre-monsoon (N=25)			During-monsoon (N=25)			Post-monsoon (N=25)		
	Min.	**Max.**	**Mean**	**Min.**	**Max.**	**Mean**	**Min.**	**Max.**	**Mean**
pH	6.9	8.1	7.7	6.7	7.7	7.3	6.7	7.9	7.3
EC (µS/cm)	218.70	832.70	528.18	200.00	1020.00	507.22	215.40	866.70	508.18
TDS (mg/l)	146.53	557.91	353.88	134.00	683.40	339.83	144.32	580.69	340.44
Cl^- (mg/l)	19.45	85.95	49.30	12.00	130.96	44.26	12.00	127.96	47.26
HCO_3^- (mg/l)	256.27	744.40	412.47	237.96	707.79	421.74	134.23	610.16	350.96
SO_4^{2-} (mg/l)	27.52	479.20	123.54	18.00	459.20	105.03	20.00	466.00	110.78
TH as $CaCO_3$ (mg/l)	50.00	470.00	247.60	48.00	640.00	357.68	40.00	630.00	345.44
Ca^{2+} (mg/l)	4.00	104.20	37.15	15.45	154.30	70.71	8.00	137.87	58.81
Mg^{2+} (mg/l)	3.05	65.54	37.57	1.27	123.83	43.98	1.66	134.52	48.22
Na^+ (mg/l)	33.40	178.00	85.89	25.76	163.00	77.10	27.30	158.40	77.10
K^+ (mg/l)	0.30	11.10	3.30	0.20	12.00	3.41	0.10	11.80	3.20

Table 2: Classification of irrigation water quality based on EC value during pre, post and monsoon season.

Parameters	Water type	Quality	Suitability for irrigation	% Samples		
				Pre-Monsoon	Monsoon	Post – Monsoon
EC (Wilcox 1955)	Low salinity water (C1) <250	Excellent	Suitable for all types of crops and soils	4	12	8
	Medium salinity water (C2) 250-750	Good	Can be used if a moderate amount of leaching occurs. Normal salt tolerant plant can be grown without much salinity control	80	68	80
	High salinity water (C3) 750-2250	Doubtful	Unsuitable for soil with restricted drainage	16	20	12
	Very high salinity water (C4) >2250	Unsuitable	Unsuitable for irrigation	-	-	-

Table 3: Statistical summary of the calculated different irrigation water quality at pre, during and post monsoon season of the study area.

Sample	Descriptive Statistics	SAR	% Na	PI %	KR	MHR	RSC	PS	RSBC	TH (mg/l)
Pre-monsoon	Min.	1.57	27.68	47.03	0.38	16.55	-3.00	1.04	0.90	50.00
	Max.	4.90	61.28	152.20	1.55	96.00	9.00	6.87	10.70	470.00
	Ave.	2.47	45.03	77.40	0.85	62.00	1.81	2.68	4.91	247.60
monsoon	Min.	0.91	17.05	34.45	0.19	2.55	-7.19	0.78	-2.10	48.00
	Max.	3.64	56.57	154.72	1.26	83.59	8.00	6.25	8.30	640.00
	Ave.	1.91	35.15	63.44	0.58	43.26	-0.24	2.34	3.38	357.68
Post-monsoon	Min.	0.99	17.84	34.94	0.21	3.42	-7.29	0.76	-1.88	40.00
	Max.	3.94	61.95	160.40	1.52	88.90	6.80	6.96	7.20	630.00
	Ave.	2.00	37.21	64.81	0.66	48.66	-1.15	2.49	2.82	345.44

Table 4: Irrigation water quality parameters and their percent contribution in the study area.

Parameters	Category	Water types	% Samples		
			Pre-monsoon	Monsoon	Post-monsoon
PI (Doneen 1964)	>75	Excellent	60	28	36
	75-25	Good	40	72	64
	<25	Unsuitable	-		-
KR (Kelley 1940)	<1	Suitable	68	92	76
	>1	Unsuitable	32	8	24
MHR (Raghunath 1987)	<50	Suitable	36	48	40
	>50	Unsuitable	64	52	60
% Na (Wilcox 1955)	<20	Excellent	-	16	12
	20-40	Good	32	44	48
	40-60	Permissible	60	40	32
	60-80	Doubtful	8	-	8
	>80	Unsuitable	-	-	-
% Na (Eaton 1950)	<60	Safe	92	100	92
	>60	Unsafe	8	-	8
RSC (Eaton 1950)	<1.25	Good	36	68	80
	1.25-2.25	Doubtful	20	20	4
	>2.25	Unsuitable	44	12	16
PS (Doneen 1962)	<3	Suitable	72	68	64
	3-5	Good to injurious	16	24	24
	>5	Injurious to unsatisfactory	12	8	12
Total Hardness (mg/l) (Karakus and Yildiz 2019)	0-75	Soft	4	4	4
	75-150	Moderately Hard	4	-	4
	150-300	Hard	72	40	44
	>300	Very Hard	20	56	48
RSBC (Eaton 1950)	<5	Safe	60	76	92

	5-10	Marginal	36	24	8
	>10	Unsatisfactory	4	-	-

Table 5: Classification of irrigation water quality index for irrigation suitability of study area.

IWQI value	Class	% Samples		
		Pre-monsoon	Monsoon	Post-monsoon
0-25	Excellent	8	12	12
26-50	Good	8	24	36
51-75	Poor	16	16	4
76-100	Very poor	20	-	-
>100	Unsuitable	48	48	48

Figures

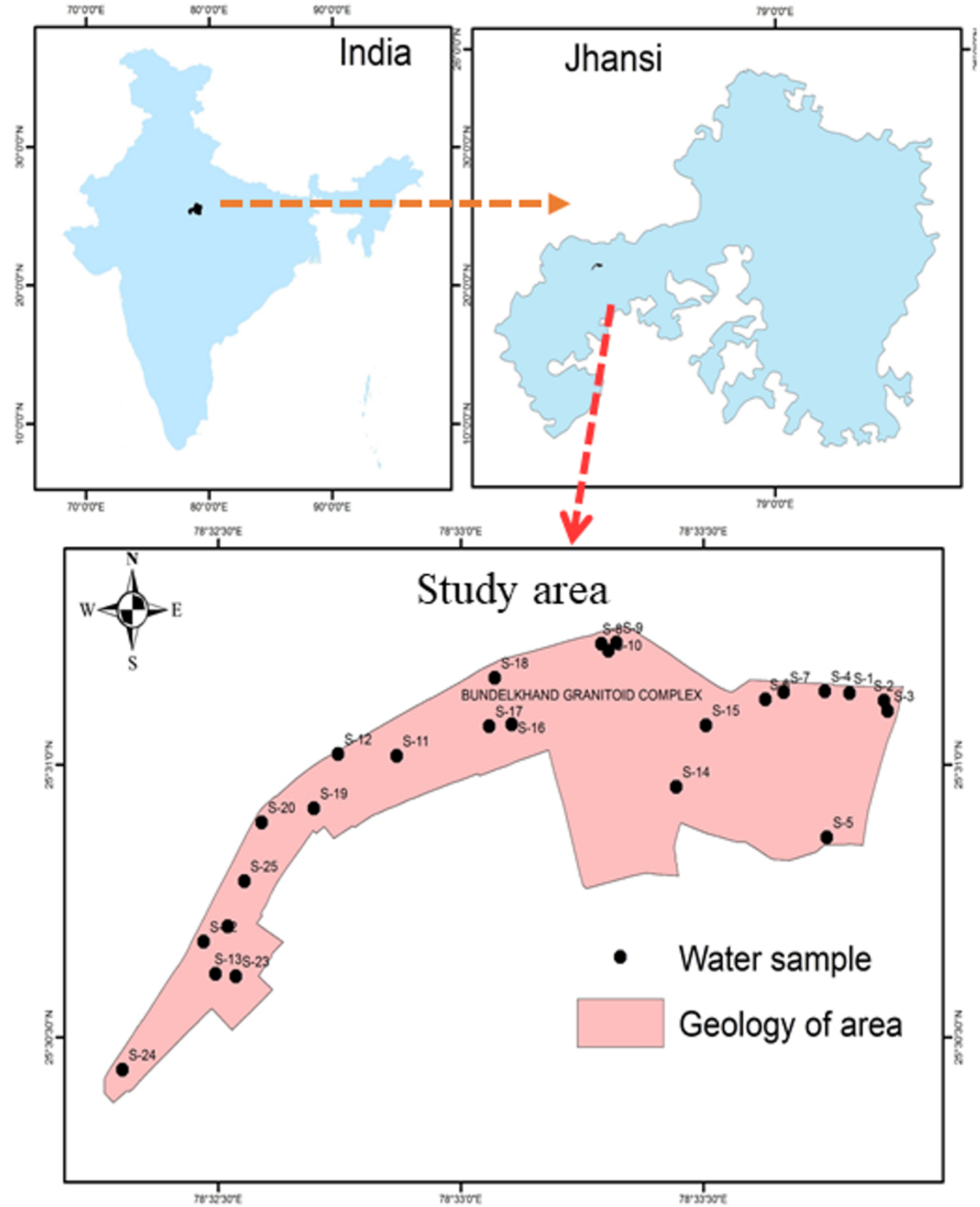

Figure 1

Different sampling location of water in the study area.

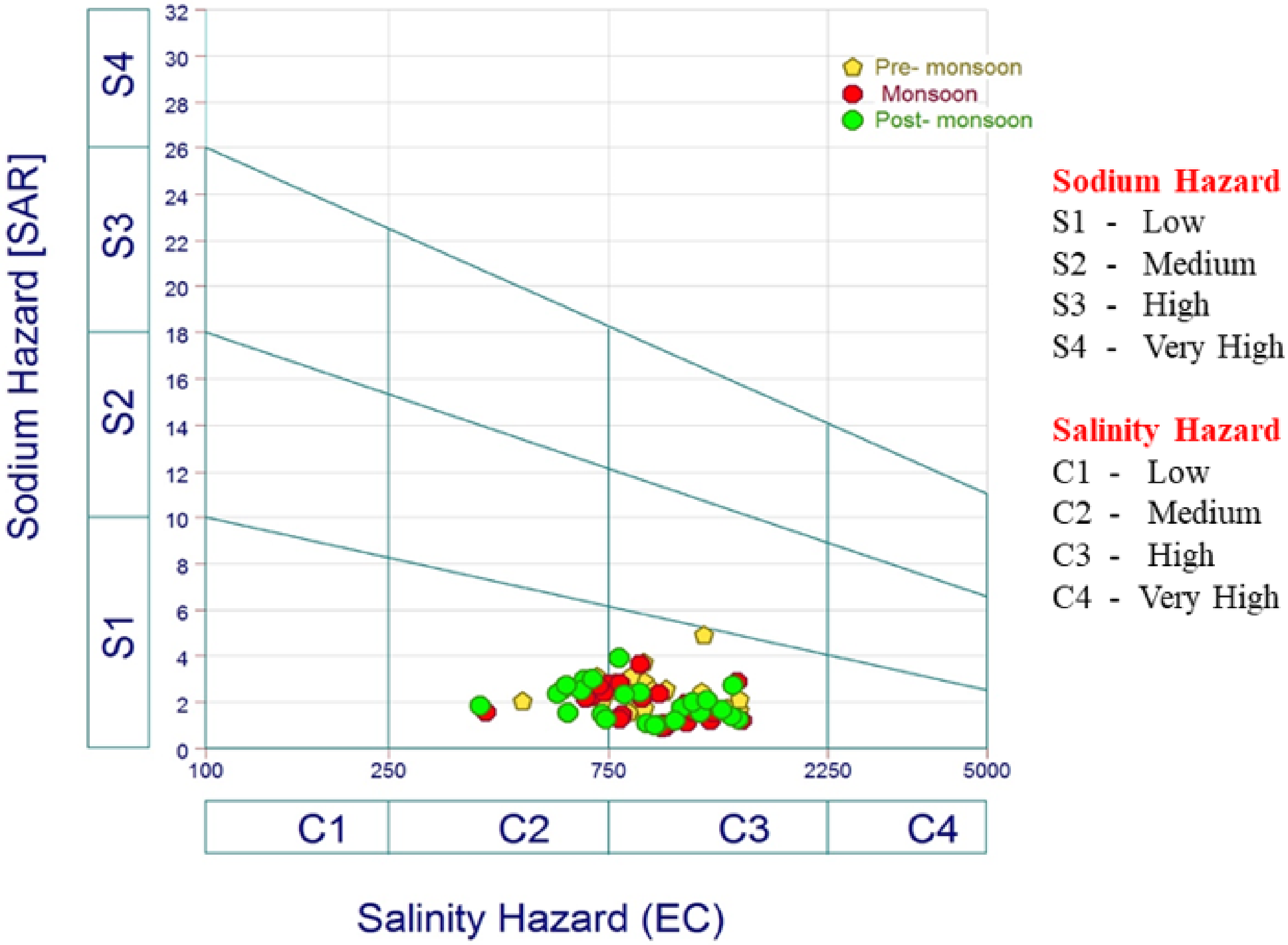

Figure 2

USSL diagram of the irrigation water suitability

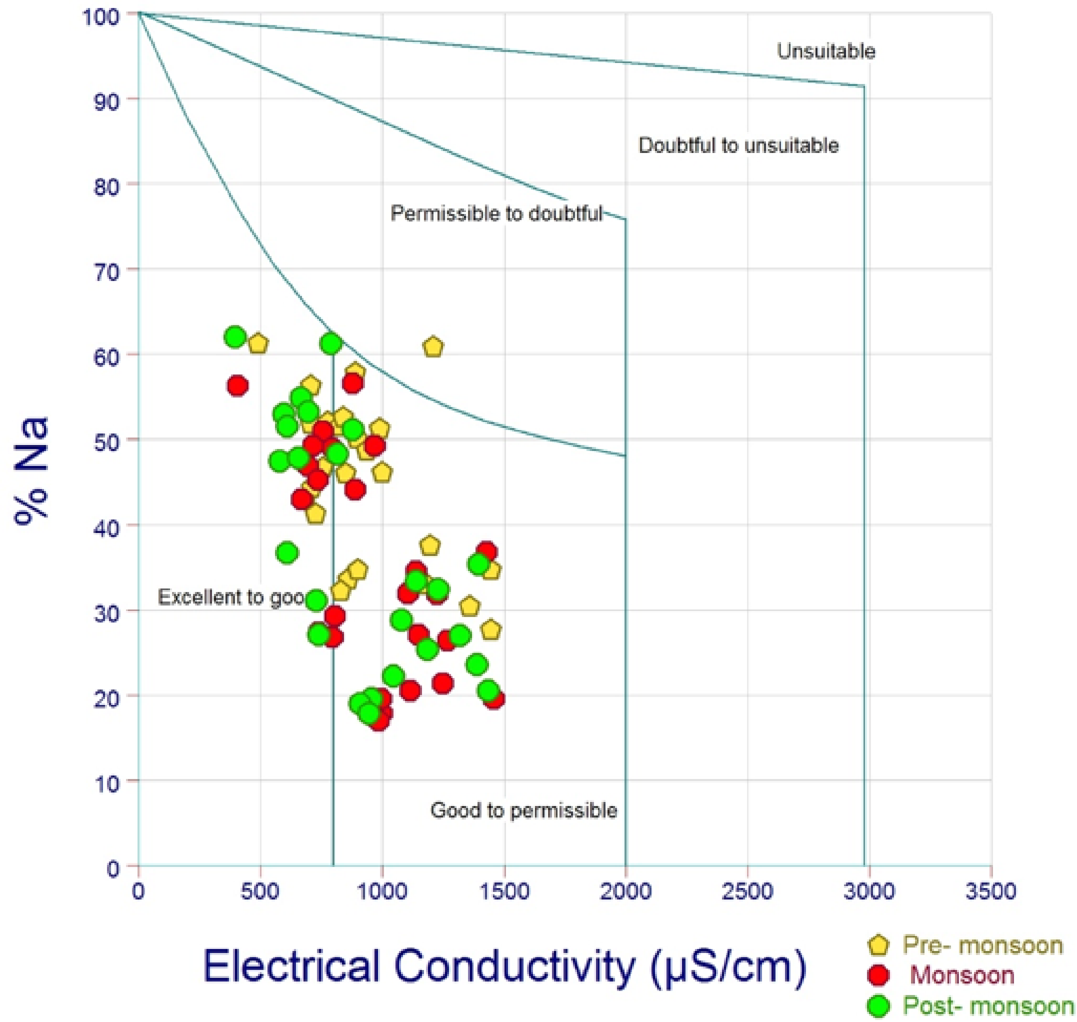

Figure 3

Wilcox diagram of irrigation water suitability.

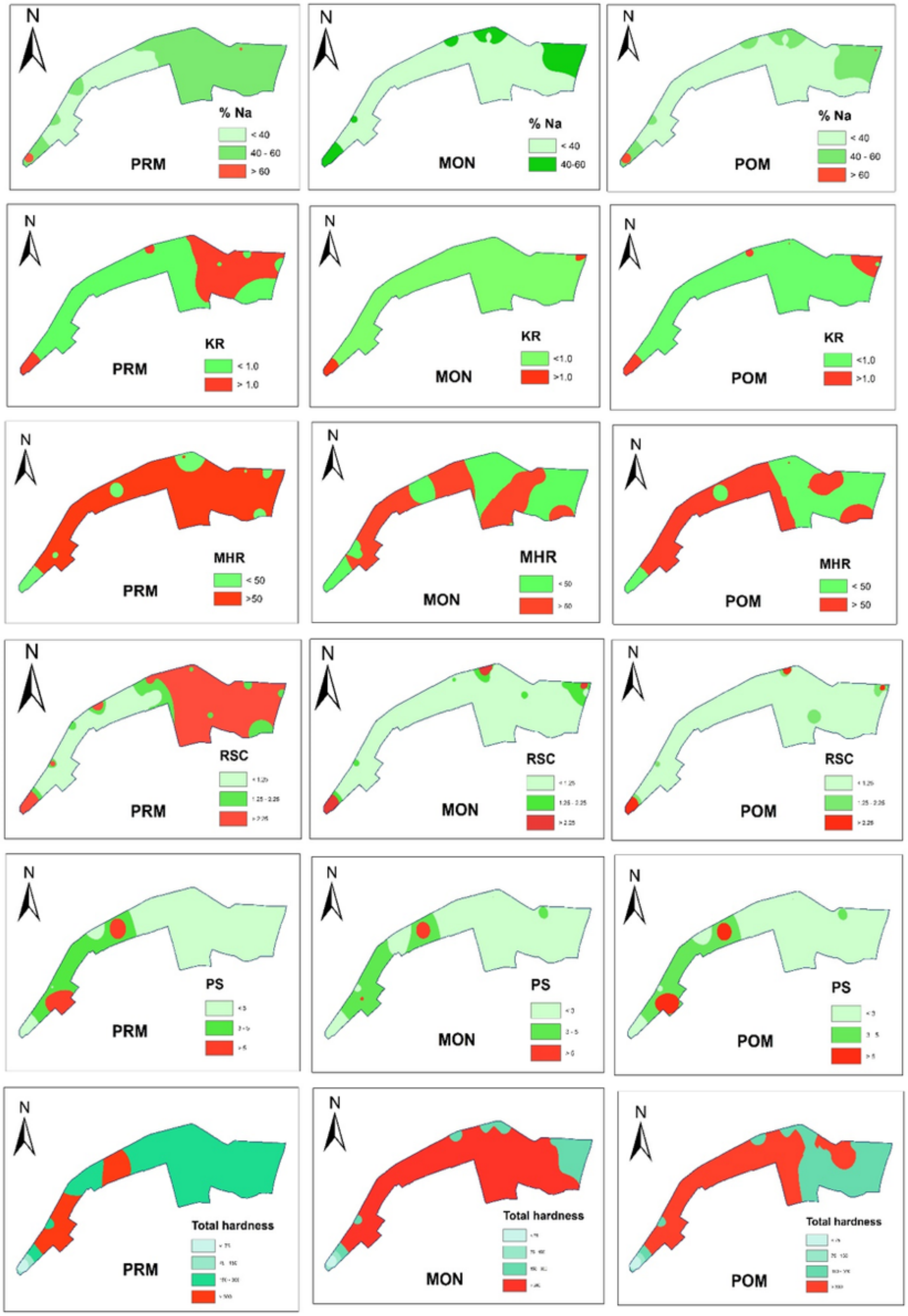

Figure 4

Spatio-temporal distribution of irrigation water quality in the study area.

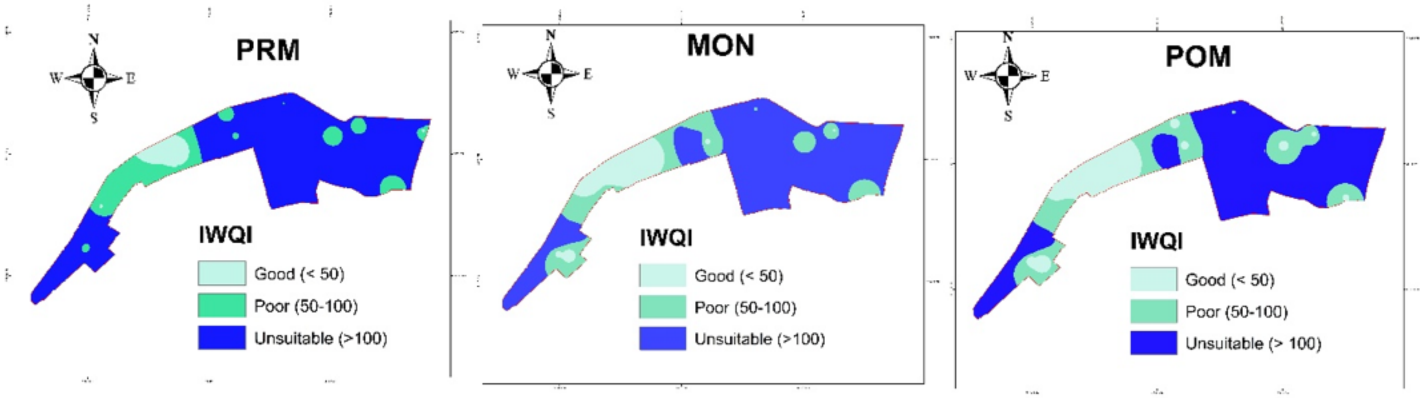

Figure 5

Spatial and temporal distribution of IWQI in the study area.

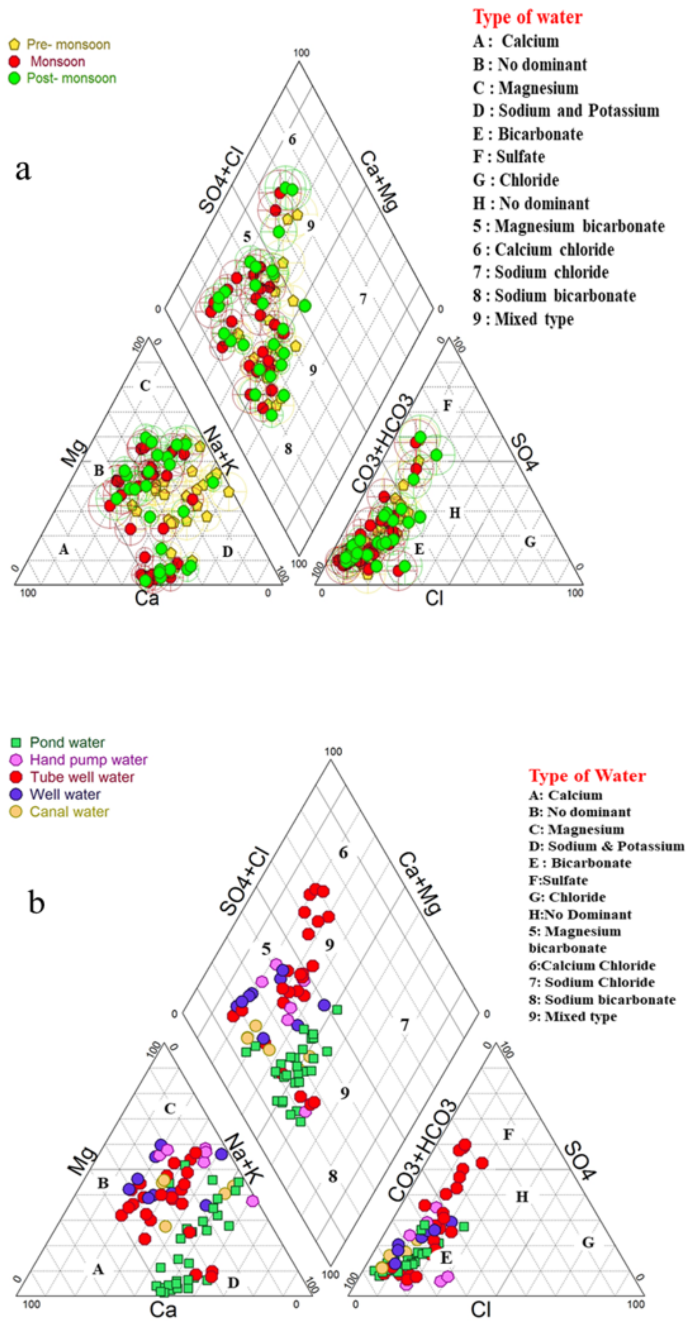

Figure 6

Piper trilinear diagram of sampled water in the study area **a**) season wise and **b**) source wise.

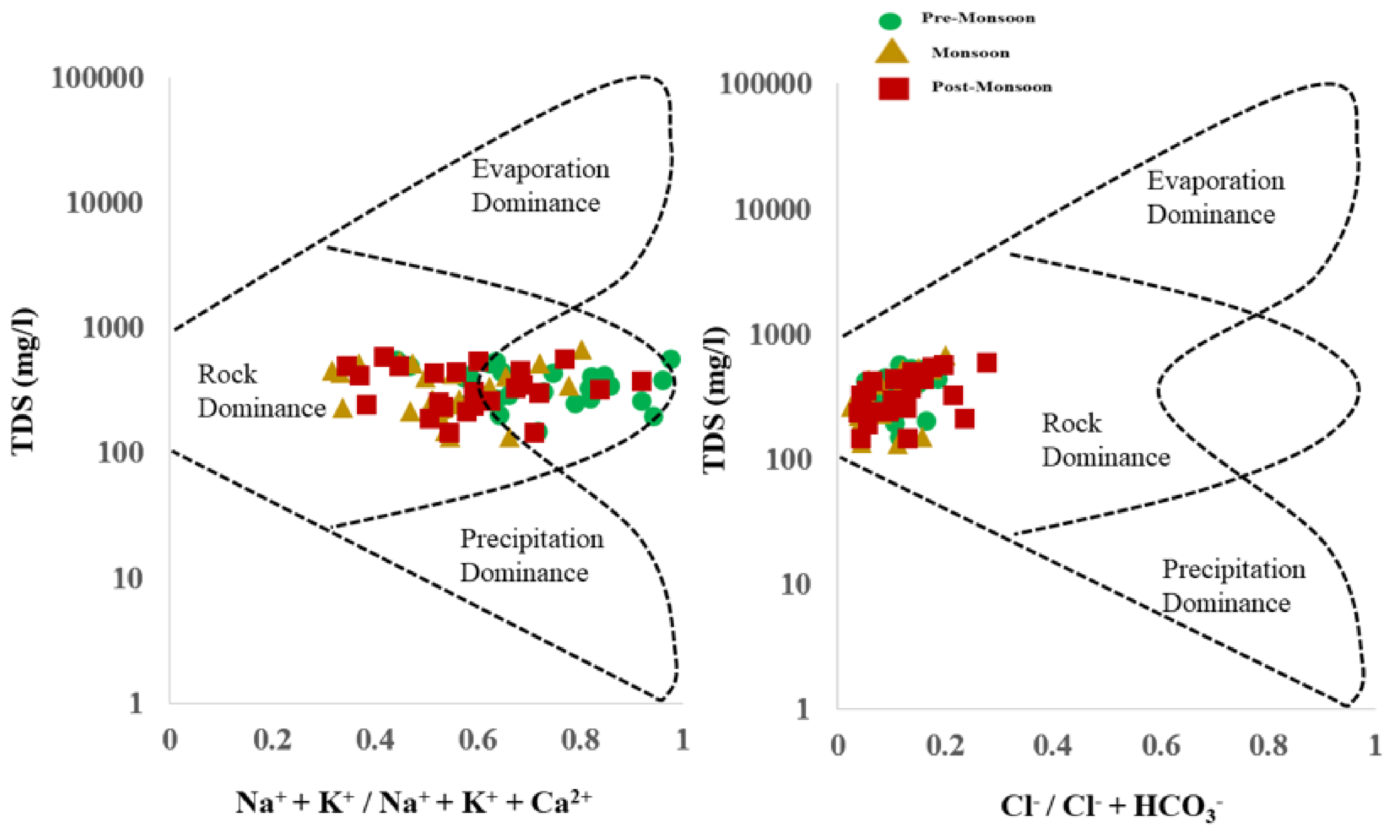

Figure 7

Gibbs plot of the different collected water samples from the study area.

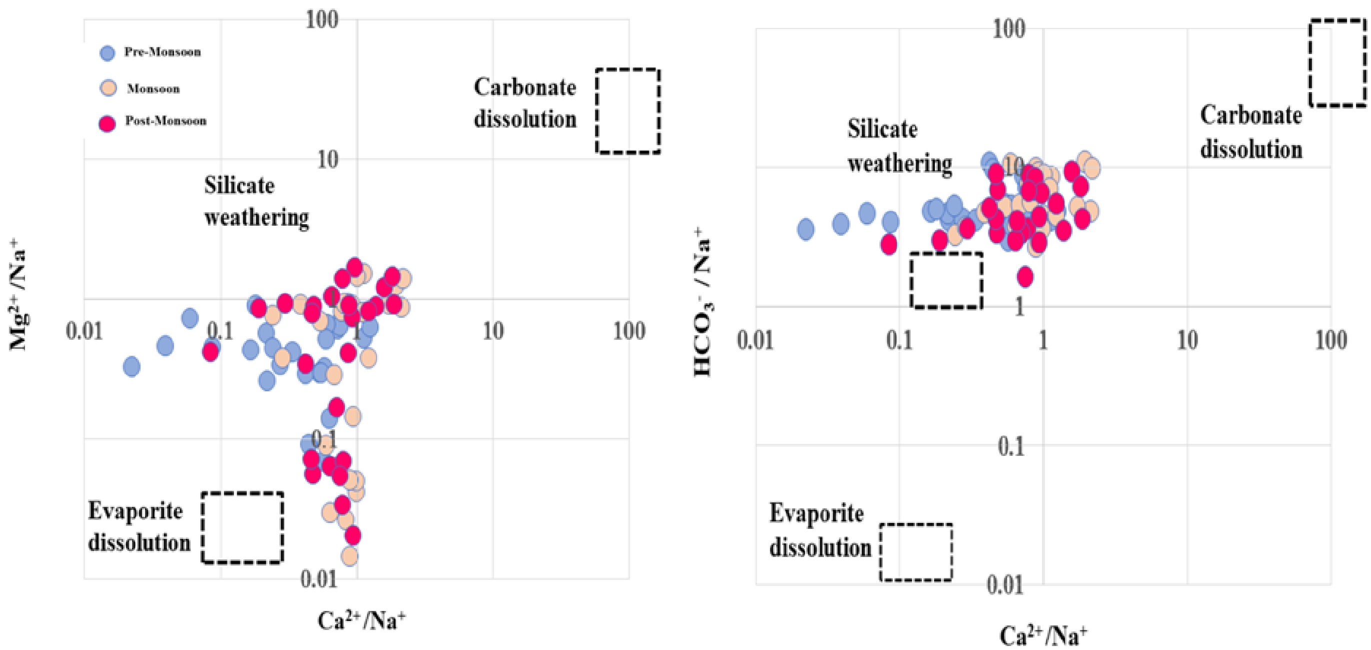

Figure 8

Plot between the Ca^{2+}/Na^{+} vs Mg^{2+}/Na^{+} and Ca^{2+}/Na^{+} vs HCO_3^{-}/Na^{+} in the study area.

Supplementary Files

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- SupplementaryTable.docx